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QUANTITATIVE ASSESSMENT OF EMERGENT BIOMASS AND

SPECIES COMPOSITION IN TIDAL WETLANDS USING

REMOTE SENSING

Abstract

Modeling and other techniques applied to quantitative assessment of
wetland energy and nutrient flux depend, in part, upon accurate data on
vegetative species composition and primary production.   Remote sensing
techniques have been applied to mapping of emergent wetland vegetation
but not to quantitative measurement of emergent plant biomass.

Recent research in the tidal wetlands of Delaware has shown that
spectral canopy reflectance properties can be used to measure the emergent
green and total biomass of Spartina alterniflora (Salt Marsh Cord Grass)
periodically throughout the peak growing season (April through September
in Delaware).   Such measurements could be applied to calculations of net
aerial primary productivity for large areas of S. alterniflora marsh in
which conventional harvest techniques may be prohibitively time consuming.
The method is species specific and therefore requires accurate discrimin-
ation of S. alterniflora from other cover types.   Exploitation of seasonal
changes in species spectral signatures is shown to have potential for im-
proving multi-spectral categorization of wetland cover types in Delaware.

The study was conducted using multi-spectral reflectance measure-
ments in the four LANDSAT/MSS wavebands (4: 0.5-0.6µm; 5: 0.6-0.7µm; 6:
0.7-0.8µm; and 7: 0.8-1.1µm) but has implications for other remote plat-
forms or use of hand-held instruments in the field.
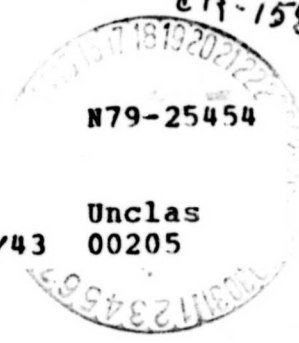
Introduction

The quantitative assessment of wetland processes, either through digital modeling or other means, relies heavily on actual measurement of characteristics of the natural system. Even the most deterministic of models generally require real data for establishment of initial conditions and testing of model outputs. In practice, ecological or modeling theory is not always adequate to simulate natural interactions, requiring an empirical approach based on actual measurements. In either case, acquiring the needed measurements in the field can be a task of major proportions. As a result, the investigator is often confronted with inadequate information and must extensively extrapolate, in space and/or time, the data available to him.

Efforts to accumulate data concerning tidal wetlands have recently come to rely more and more on remote sensing techniques. These techniques have been extensively developed for the characterization of emergent vegetation -- an important part of the wetlands ecosystem. Remote sensing is now routinely used to identify wetland boundaries because of the large reduction in time and effort achieved over that required by conventional surveys. Remote sensing has not, however, been extensively utilized to assess the function of the wetlands ecosystem; primarily because the methodology has not progressed far beyond the relatively modest task of distinguishing wetlands from non-wetlands or of identifying major plant communities within the marsh. Knowledge of the complex interactions between the electromagnetic radiation measured by remote sensing devices and the marsh plant cover is substantially lacking. Nevertheless, such knowledge is critical if quantitative evaluation of wetlands is to be extended beyond the mapping/inventory phase.

The emergent grasses and rushes of tidal wetlands bear a considerable resemblance to many terrestrial vegetation types to which rigorous remote sensing research has been more extensively applied. Applied studies using field radiometers and Landsat/MSS data have generally concluded that reflectance measurements in the near-infrared spectral region ($0.75\mu m$-$1.35\mu m$) and in the red region ($0.6\mu m$-$0.7\mu m$) can be used to estimate vegetative variables related to biomass (Leaf Area Index-LAI, stem density or biomass itself). Measurements in the Landsat/MSS Band 5 (red - $0.6\mu m$ to $0.7\mu m$) region are inversely related to the amount of green biomass because of chlorophyll absorption of radiation in this waveband. Seevers et al. (1975) found that grass biomass estimates for rangeland management could be based on MSS Band 5 radiance measurements extracted from Landsat digital tapes. Pearson and Miller (1972) describe an inverse relationship between total grassland biomass and in situ reflectance measurements at $0.68\mu m$ ($r=-0.7$) but report a better, positive correlation of infrared reflectance with total biomass ($r=0.84$). Pearson and Miller propose that, as measurements in these two spectral regions respond with opposite trends to increasing biomass, some combination of the two bands might produce a more sensitive response than is present in either single band. The difference in reflectance at the two wavelengths and the ratio of the two reflectances were both found to correlate with biomass more highly than did reflectance in either band alone. Most impressive is the case of the infrared/red ratio which yielded a correlation coefficient of 0.95 when linearly correlated with the amount of green biomass in the sample plots.

If similar relationships are observed for tidal wetland vegetation, considerable contributions might be made to data acquisition efforts through synoptic, cost effective remote sensing techniques.

Dependance of Wetland Spectral Reflectance Characteristics on

Canopy Parameters - Including Biomass

Several research groups and regional authorities have applied analysis
of remotely sensed data to map or inventory tidal wetland resources
(Anderson et al., 1973; Bankston, 1975; Butera, 1975; Carter and Anderson,
1972; Carter and Schubert, 1974; Erb, 1974; Gordon et al., 1975; Klemas
et al., 1975; Bartlett et al., 1976; Pfieffer et al., 1973; Reimold et al.,
1972; Stroud and Cooper, 1968; Thompson et al., 1974). Some used Landsat/
MSS data (Bankston, 1975; Erb, 1974; Gordon et al., 1975; Klemas et al.,
1975; Anderson et al., 1973; Carter and Schubert, 1974) while the others
relied on aerial photography or scanner data to distinguish major vege-
tation communities in coastal areas. Carter (1978) has written an excellent
review of current remote sensing applications in wetlands.

In a few cases, efforts have been directed at collection of biomass
information. Carter (1976) used measurements of the areal extent of major
plant species based on interpretation of Landsat data along with typical
values for primary production of each species to estimate primary production
for a marsh island in Virginia. Such estimates are limited, however, in
that large intraspecific variations in production, even within a small area,
are known to occur. Reimold, et al., (1973) found that tonal variations
of Spartina alterniflora recorded on aerial color infrared film could be
associated with variations in emergent biomass. Increases in the relative
intensity of infrared reflectance of stands having larger amounts of biomass
produced "redder" image tones. The relationship observed was a somewhat
qualitative one but illustrated the potential for more accurate work based
on more easily quantifiable radiometric data.

An investigation has been carried out in Delaware's wetlands, the
objective of which was to quantify the interactions of wetland grass canopies

with electro-magnetic radiation and to assess the potential for remote sensing of emergent biomass or other canopy parameters useful in ecological characterization of the environment. In situ radiometric measurements and digital modeling were used to evaluate the physical and biotic factors controlling the spectral reflectance signatures observed in the four Landsat/MSS wavebands (Band 4: 0.5μm - 0.6μm; Band 5: 0.6μm - 0.7μm; Band 6: 0.7μm - 0.8μm; Band 7: 0.8μm - 1.1μm). Landsat was chosen because of the availability of data and the anticipation that it would be useful for repetitive evaluation of large areas of wetland at low cost. Three grass species were examined: Spartina patens, Distichlis spicata and Spartina alterniflora. In the interests of brevity, results will be presented primarily for S. alterniflora which is the dominant species in Delaware and for which spectral relationships seemed to be most clearly expressed. Digital simulation of canopy interactions with electro-magnetic radiation was carried out for this species using the model developed by Suits (1972).

Field studies showed that canopy reflectance measurements in the visible spectral region (MSS Bands 4 and 5) were inversely related to the percentage, by weight, of green vegetation within the canopy. This result was partic-ularly evident in the heavy chlorophyll absorption region of Band 5 (0.6μm - 0.7μm)(Figure 1). Digital simulation confirmed this functional dependance and showed little response in the infrared Bands 6 and 7 (Figure 2). Infrared canopy reflectance appeared to be related to several measures of the amount of vegetation present in the canopy, including total and green biomass and canopy height (i.e. vertical distance from top of canopy to soil). Canopy reflectance for S. alterniflora in MSS Band 7 (0.8μm - 1.1μm) was best correlated with canopy height (Figure 3) although regression relationships

were generally weaker for infrared reflectance than visible. Digital modeling indicated a functional response of infrared reflectance to changing horizontal leaf area index (horizontally projected area of vegetation per unit area of ground)(Figure 4). Leaf area index is presumably proportional to the field measurements related to amount of vegetation - i.e., biomass and canopy height. Except at very small values of leaf area index, visible canopy reflectance (Bands 4 and 5) is insensitive to this parameter (Figure 4).

By ratioing infrared/red canopy reflectance a parameter results which is proportional to green biomass of the canopy. As was the case for rangeland grasses (Pearson and Miller, 1972), regression produces high correlation (r = .90) of ratioed reflectance with green biomass (Figure 5). A significant aspect of the relationship observed for S. alterniflora is its linearity over a very wide range of green biomass values: 20 - 1000 g dry wt/m^2 (Figure 5) indicating great potential for use of spectral data for estimation of this parameter.

Spectral measurements were not as highly correlated with green biomass for the other two species tested: S. patens and D. spicata. This may result from variability in growth form (vertical versus lodged stands) and from the high stem densities (limiting penetration of radiation into the canopy) which are characteristic of these species. Drake (1976) made in situ spectral measurements of S. patens, D. spicata and Scirpus olneyi and found high correlations of red (0.66μm - 0.71μm) reflectance with green biomass (r^2 = 0.74 - 0.83). The range of biomass tested was restricted, however (0-350 g dry wt./m^2). It seems likely that Drake's results were produced by high intercorrelation between the percentage and the mass of green vegetation. Similar results, using visible reflectance alone have been reported in Western rangelands (Seevers et al., 1975).

Additional Considerations for Remote Sensing of Emergent Wetland Biomass

There are several further considerations involved in assessing the potential for spectral, remote sensing estimation of wetland biomass.

Thus far, potential for accurate biomass estimation using Landsat spectral wavebands is established only for S. alterniflora although Drake's (1976) study indicates some utility of other wavebands for other species. If input to models simulating estuarine particulate detrital flux is desired, however, S. alterniflora is probably the most important source among the emergent plants owing to its large areal extent, high productivity and regular exposure to tidal flow. Thus, significant contributions could be made through synoptic, periodic monitoring of this species alone.

The regression relationship used for estimation of green biomass (Figure 5) is subject to approximately 2-3 times less accuracy in estimation of biomass for each sample quadrat than is the conventional harvest technique. This means that large spectral samples (i.e. large N's) must be collected in order to achieve accuracies in estimation of mean biomass which are comparable to those available through harvest techniques. A significant characteristic of spectral data collection, however, is the comparative ease with which large samples are accumulated. Digital analysis of Landsat data is particularly advantageous in this respect although even in situ radiometric measurements can be made rapidly enough to offset the need for large samples. Furthermore, the resources required for large scale harvesting are such that measured quadrats may be absent altogether in many areas or spread so thinly that even large scale heterogenities in biomass are missed. In situ radiometry has the added advantage of providing useful data in real time. The significant degradation in precision of spectral biomass estimation for individual plots can, therefore, be compensated for

by collection of many more samples within a given area than may be
feasible using harvest techniques. If Landsat data is used, the number
of samples that can be analyzed within a given area is theoretically
limited only by the size of the area of interest with respect to a Landsat
picture element (pixel); i.e. $N = \dfrac{\text{size of wetland area}}{\text{size of Landsat pixel (.44) hectare}}$.

As the biomass estimation function is species - specific, accurate
discrimination of S. alterniflora from other wetland cover-types is required
prior to analysis. Such discrimination can be based on Landsat data although
some misclassification may result (Bartlett, et al., 1977; Carter, 1978).
Recent research indicates that use of multi-seasonal data or exploitation of
seasonal changes in interspecific seasonal contrast can enhance classif-
ication accuracy (Bartlett, 1979; Butera, 1978; Carter and Schubert, 1974).

As quantitative surface reflectance data is required for biomass
estimation, Landsat measurements must be corrected for effects of sun angle
and atmospheric attenuation of the upwelling signal. Techniques for atmos-
pheric correction of Landsat data have been successfully applied but are
not without some inaccuracies (Bartlett et al., 1977; Rogers, et al., 1973).

Finally, calculations of emergent primary production require periodic
measurements of various components of standing stock biomass. Landsat can
provide effective repetitive coverage but frequency of coverage is subject
to cloud cover limitations. However, several of the most common method-
ologies for estimating primary production are amenable to the type of data
on green and total biomass available through spectral techniques, including
those of Milner and Hughes (1968) and Smalley (1959). Only the more complex
methods such as that of Wiegert and Evans (1964) require measurements or
quadrat manipulation not available from remote sensors.

Conclusions

Most efforts to evaluate characteristics of tidal wetlands and adjacent estuarine waters depend on measurements which can be difficult and time-consuming to accumulate in the field. To the extent that they can be applied, therefore, remote sensing techniques can contribute to the available data base by providing synoptic, cost-effective information about the environment. An important component of the coastal environment is the emergent vegetation of tidal wetlands. Remote sensing has established utility in delineation of wetland boundaries and areal extent and is now routinely applied to such tasks by federal and state management authorities and many research groups.

Recent research indicates that spectral measurements made by existing sensors such as Landsat/MSS contain information on the standing crop, emergent biomass of selected wetland plants. Assessment of large areas of S. alterniflora marsh, in particular, appears to have the potential to benefit from spectral techniques including in situ radiometry and analysis of Landsat/MSS data. Biomass estimation may be limited for other species and analysis of S. alterniflora is subject to restrictions in species identification, spatial resolution and correction for atmospheric effects on the measured spectral signal. Nevertheless, the large advantages which would accrue from rapid, repetitive, cost-effective assessment of large expanses of tidal wetland should motivate continued development and extension of remote sensing techniques beyond simple mapping tasks. Routine monitoring of biomass and productivity in wetlands using remote sensing would provide valuable management information as well as contributing data to modeling and other research efforts.

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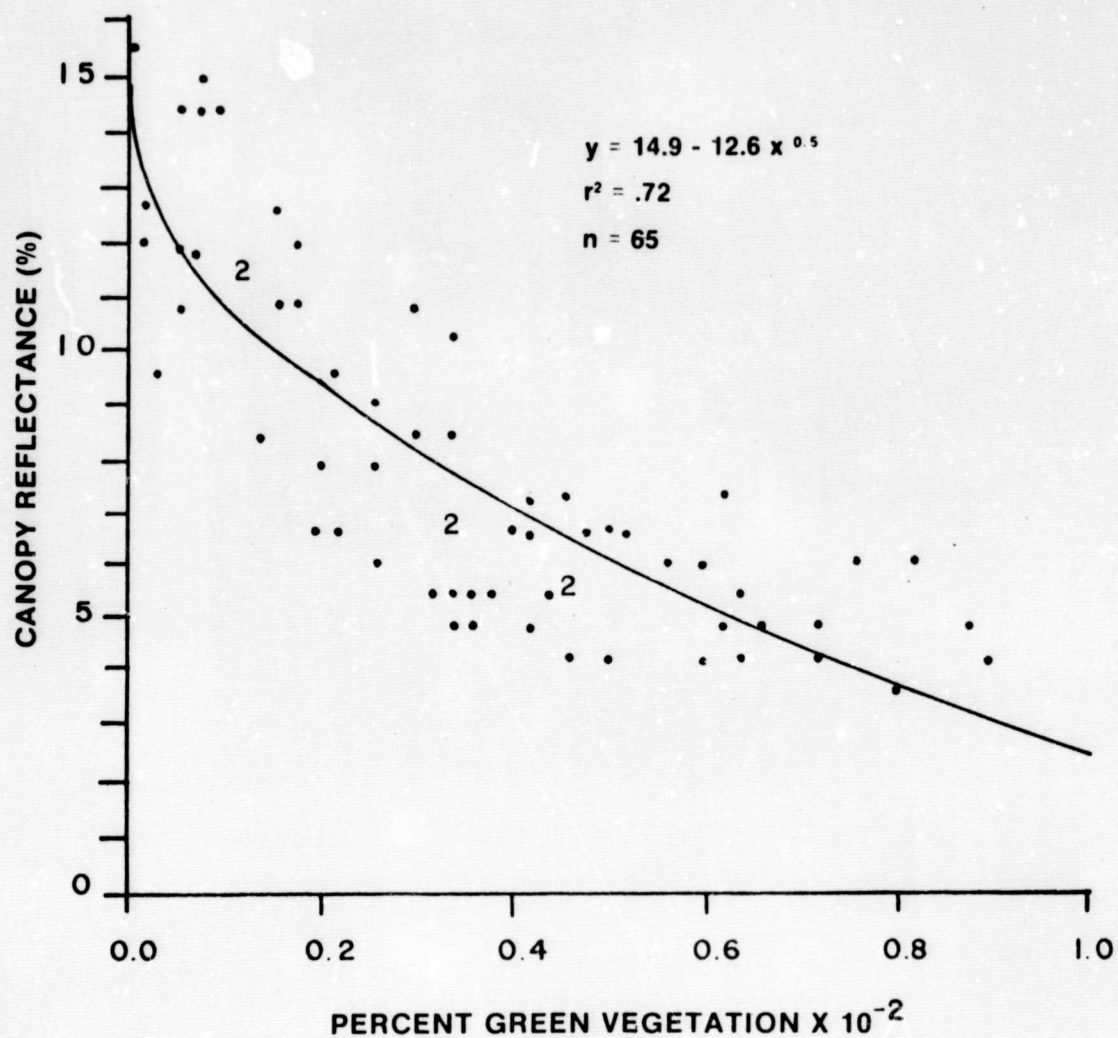
Figure 1.--Plot of Band 5 (0.6μm–0.7μm) canopy reflectance vs. percent green vegetation for S. alterniflora. Regression results are shown.
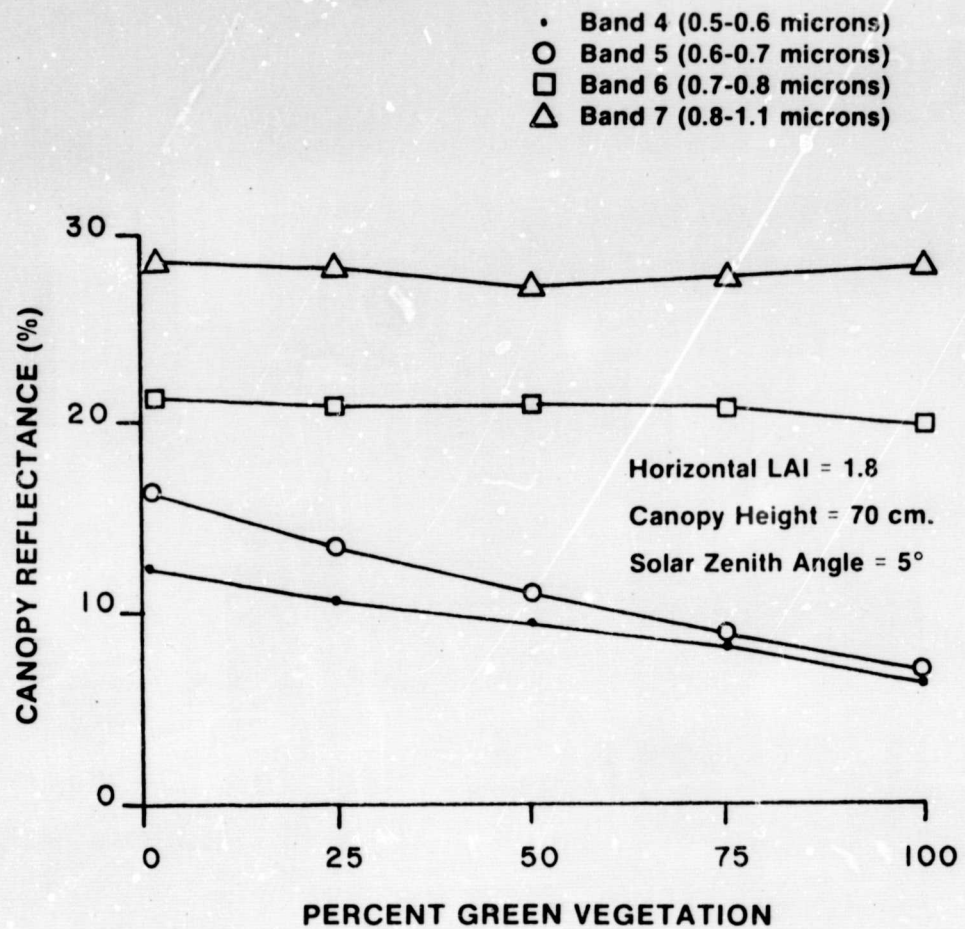
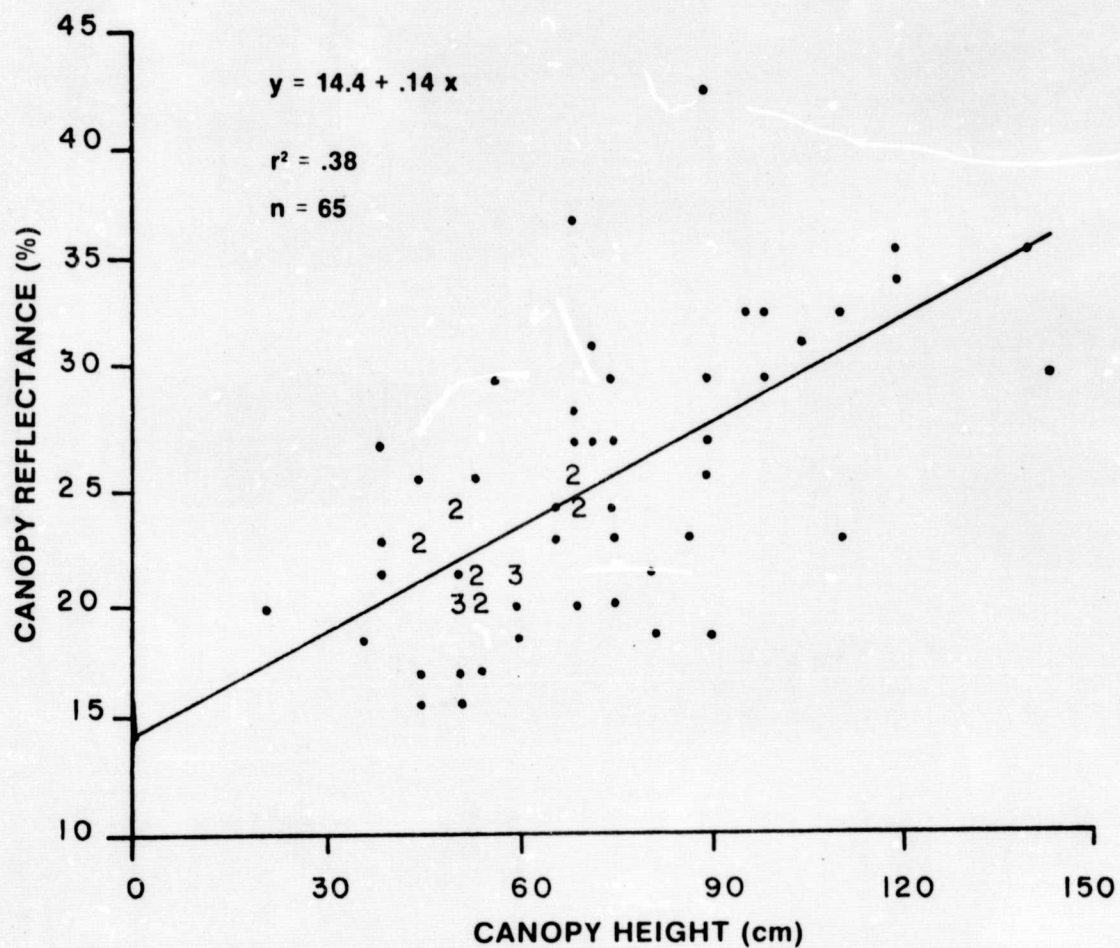Figure 2 --Simulated response of S. alterniflora canopy reflectance to changing percentage of green vegetation.

Figure 3.--Plot of Band 7 (0.8μm-1.1μm) canopy reflectance vs. canopy height for S. alterniflora. Regression results are shown.
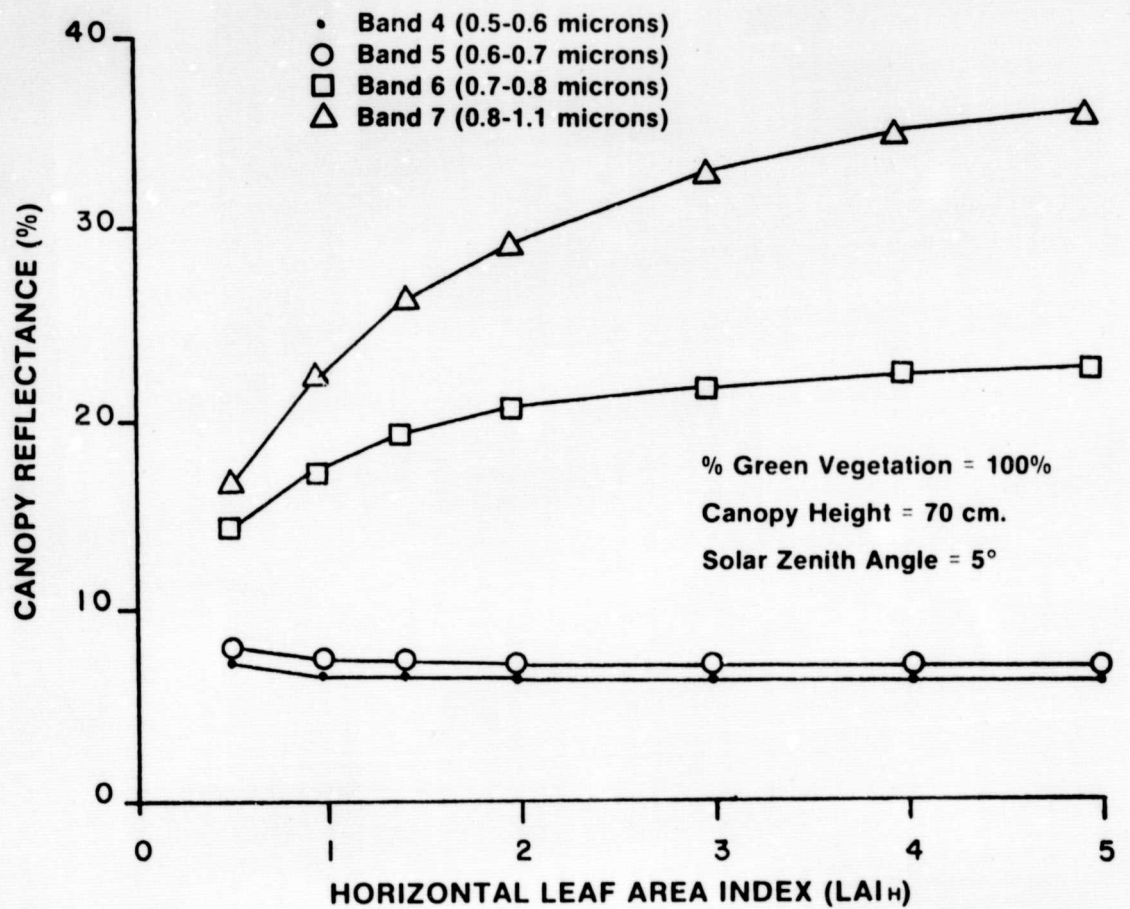
Figure 4.—Simulated response of S. alterniflora canopy reflectance to changing horizontal leaf area index (LAI$_H$).
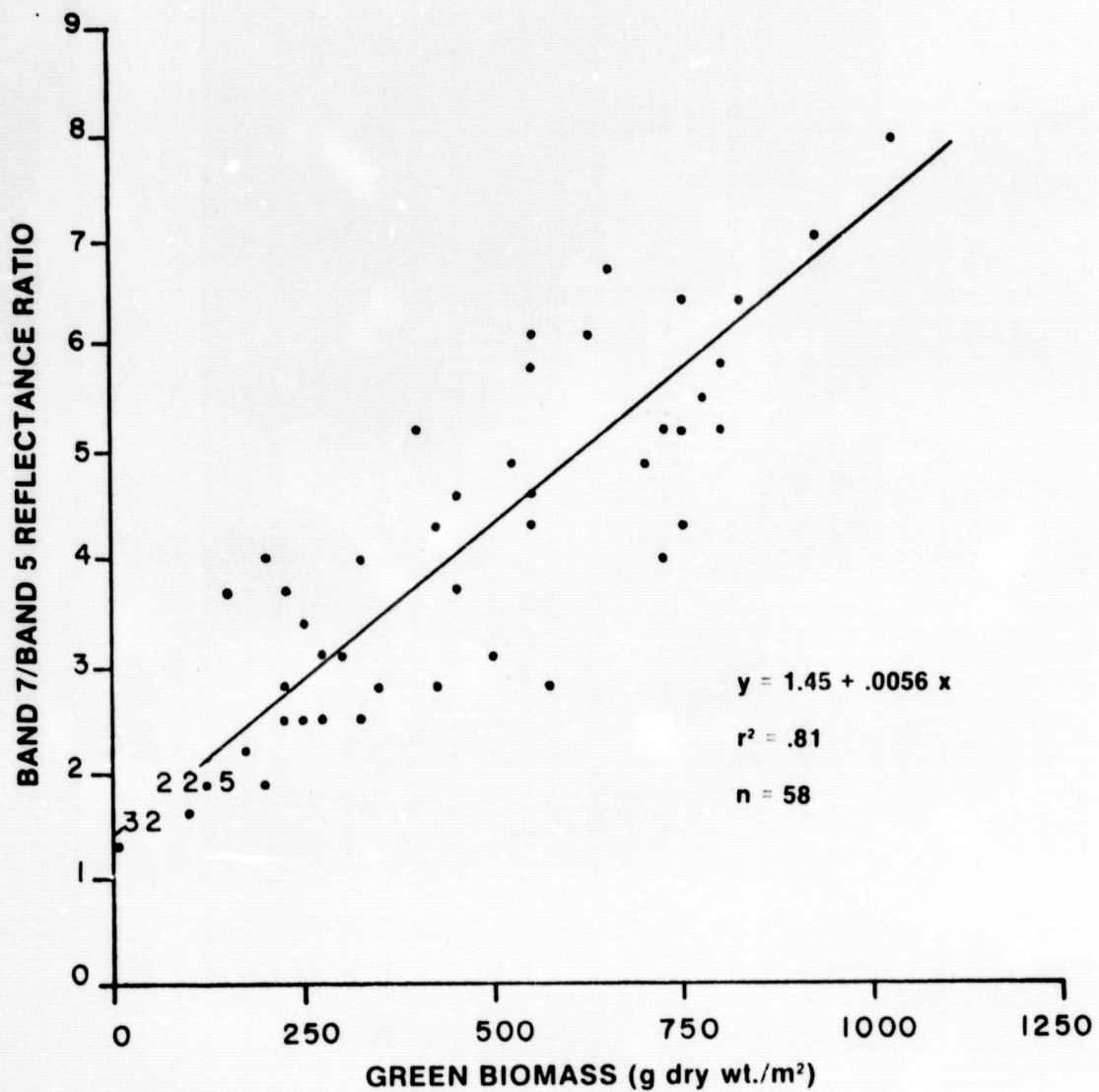
Figure 5 –Plot of Band 7/Band 5 canopy reflectance ratio vs. green biomass for S. alterniflora. Regression results are shown.